FACTORS INFLUENCING THE CHOICE OF THE POLE PITCH OF LINEAR INDUCTORS OF ELECTRODYNAMIC SEPARATORS

Bagin D.N., Bubnova M.A., Konyaev I.A., Konyaev A.Yu.

Ural Federal University, Ekaterinburg, Russia, a.u.konyaev@urfu.ru

Abstract - Features of the choice of pole pitch of linear induction machines of electrodynamic separators are considered. As criteria for this choice, indicators are used: operability, energy efficiency, selectivity of separation.

Key words - electrodynamic separator, traveling magnetic field, pole pitch of inductors, criterias of choice, research results.

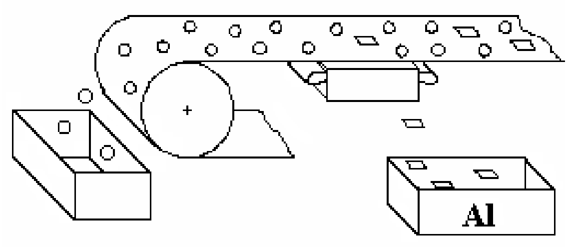
I. INTRODUCTION

The improvement of technologies for the collection and primary processing of secondary non-ferrous metals is a prerequisite for the development of secondary non-ferrous metallurgy and the establishment of solid waste processing enterprises. One such technology is electrodynamic (eddy current) separation in a traveling magnetic field. Electromagnetic forces that ensure the extraction of metal particles from the stream of metal-containing waste, in the first place, depend on the parameters of the traveling magnetic field: the amplitude of induction B_m, pole pitch τ and frequency f. In this paper, we consider factors that determine the choice of the value of the pole pitch of the inductor in separators intended for solving various technological problems.

II. ELECTRODYNAMIC SEPARATORS BASED ON LINEAR INDUCTORS

Electrodynamic separation based on interaction force of a travelling magnetic field with eddy currents induced by this field in conducting particles, is the most effective for the collection and recycling of non-ferrous metals. Separators based on linear induction machines (LIM) were widely used, the main variants of which are shown in Fig. 1. Such separators easily fit into technological lines and are used in the extraction of non-ferrous metals from various types of metal-containing solid waste (automobile scrap, mixed production and municipal waste, cable and electronic scrap, etc.), as well as in the processing of complex non-ferrous scrap in preparation it to metallurgical redistribution [1-3]. These electrodynamic separation problems can be conditionally divided into two groups. The first group includes the tasks of separating non-ferrous metals from non-metals, and the second group involves more complex tasks of sorting metals according to their physical properties. In both cases, the final results of separation depend on the combined action of electromagnetic and mechanical forces on metallic particles. This implies a solution at the design stage of two theoretical problems:

- calculation of the parameters of linear inductors, providing the necessary characteristics of the traveling magnetic field and the required electromagnetic extraction force;
- calculation of the separator as a whole based on the determination of metal particle trajectories (determination of parameters of the mechanical part of the separator and refinement of the parameters of the electromagnetic part).



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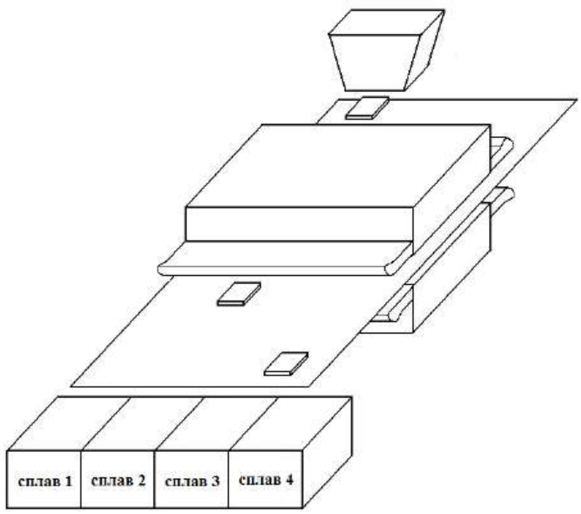

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Fig. 1. Schemes of electrodynamic separators based on LIM

In this paper special attention is paid to the choice of LIM parameters with a two-sided linear inductor, which can be used in the case of processing materials with particle sizes less than 50 mm. Features of the choice of single-sided LIM separator parameters (with an open magnetic system) were considered earlier in [3-4].

III. METHODOLOGY AND RESULTS OF THE ANALYSIS

In LIM electrodynamic separators, the role of the secondary element (CE) is performed by the conductive metal particles extracted from the separated mixtures. The specific electrical conductivity of such particles is given, and the dimensions (width a, length in the direction of motion of the field b and thickness d) are, as a rule, smaller than the pole pitch of the linear inductor τ. Such a limitation of the size of the CE causes a redistribution of the secondary currents and leads to a significant decrease in the electromagnetic forces of $F_{эм}$ [3]. Under these conditions, an increase in $F_{эм}$ is possible only due to a rational choice of the parameters of linear inductors. Taking into account the foregoing, the design of the LIM separators is reduced to determining the parameters of the traveling magnetic field required for solving the technological problem (the amplitude of induction B_m, the frequency f and the pole pitch τ) and the corresponding parameters of the linear inductor at which such a magnetic field is provided. It should be taken into account that restrictions are imposed on the choice of inductor parameters. In particular, in order to reduce the cost of creating and operating installations, customers prefer to use the power of LIM inductors from a standard industrial network with a frequency f = 50 Hz. On the other hand, the possibilities of increasing B_m are limited by the limiting electromagnetic loads of the inductors achievable with intensive air cooling of the windings.

As shown in [3-4], it is advisable to use a number of indicators as optimization criteria in the design of LIM separators: the specific electromagnetic force equal to the force-to-mass ratio of the extracted particle ($F_m = F_{em}/m$, N/kg or m/s^2) and specific electromagnetic force to the power consumption ($F_{mS} = F_m/S$, N/(kg·kVA)). The first criterion (F_m) shows the possibility of achieving maximum accelerations reported to recoverable metal particles and determines the operability of the separator. The second indicator (F_{mS}) allows evaluating the energy efficiency of the devices. In [3-4], methods for calculating the electromagnetic forces in the electrodynamic separators F_{em} and the power consumed by linear inductors from the network S are proposed and it is shown that in the case of an LIM with a one-sided inductor, the dependences of the above-mentioned indices on the variable variables (in particular, on pole pitch τ) are extremal. In this case, the choice of the pole pitch of a linear inductor reduces to finding the variants corresponding to the extreme of such dependences. For example, in the design of the electrodynamic separator KM203-M, designed to extract aluminum from the solid domestic waste stream, the pole pitch of a single-sided linear inductor τ = 186 mm was selected [5], taking into account the customer's specifications. Specific electromagnetic forces produced in such a separator when exposed to aluminum particles of different fineness (with a particle thickness d = 2 mm, γ = 29 MS/m, ρ = 2,7 g/cm^3 and the amplitude of the linear inductor current density J_{1m} = 110 kA/m) are shown in Fig. 2. Calculations are performed for three values of the distance from the surface of the inductor to the particle h = 10, 30 and 50 mm (figures on the graphs). It is not difficult to see that with increasing distance h the electromagnetic force decreases substantially. With a large capacity of the units (for example, a feed rate of 1,2 m/s and a conveyor belt width of 1 m), the force required for separation can reach 20 N/kg. With this in mind, it can be stated that particles with a particle size of less than 40 mm will not be extracted. This evaluation was confirmed in the subsequent operation of the separators [5].

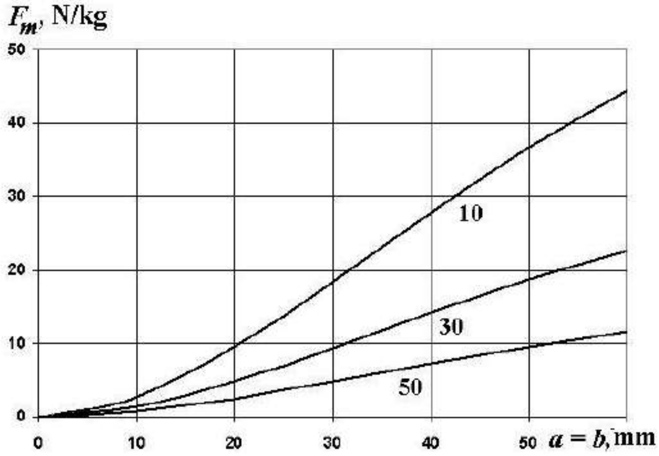

Fig.2. Dependences of the specific force F_m on the particle size for a single-sided LIM

The most rational way of increasing the specific electromagnetic forces in the separation of small-sized metal particles is the use of electrodynamics separators with a two-sided linear inductor in which the air gap δ is determined by the maximum particle size in the technological task being solved. In the case of two-sided LIMs, the $F_{em}(\tau)$ and $F_m(\tau)$ dependences remain extreme, and the character of the $F_{mS}(\tau)$ dependence varies. An example of calculation of the $F_{mS}(\tau)$ dependences for a two-sided LIM with working gaps of δ = 20, 30 and 40 mm (figures in graphs) is shown in Fig. 3. Calculations are performed at the amplitude of the linear current density (for two inductors) J_{1m} = 150 kA/m for a square aluminum plate with dimensions 40 × 40 × 4 mm.

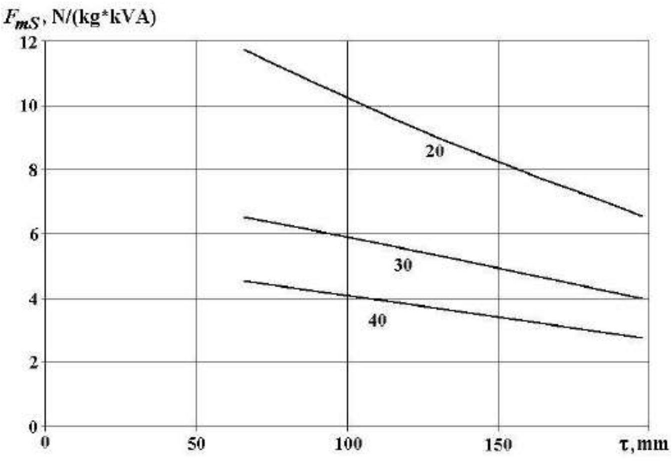

Fig.3. Dependencies of $F_{mS}(\tau)$ for a two-sided LIM

In Fig. 4 shows the dependence of the specific electromagnetic force acting on square aluminum plates of different fineness on the pole pitch of the LIM two-sided inductor at a working gap δ = 40 mm. The calculations were performed for samples of an aluminium alloy AMg3 having a conductivity of about 20 MS/m and a thickness of 3 mm. The solid lines show the curves corresponding to the distance from the surface of the inductor to the particle h = 5 mm, the dashed lines represent the curves for the particles on the axis of the gap.

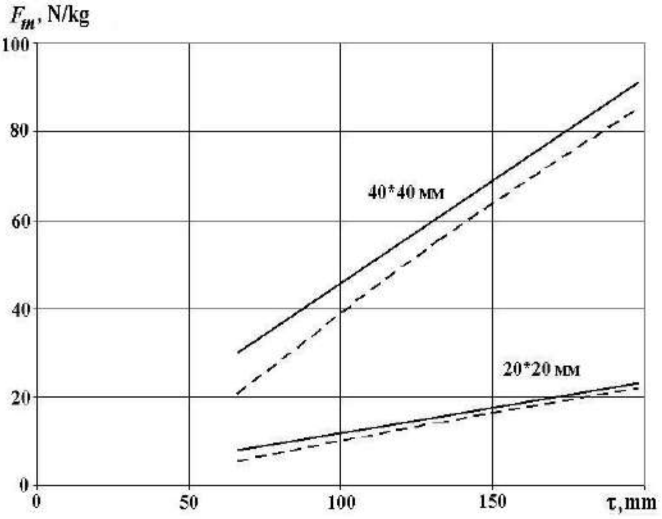

Fig. 4. Dependences of $F_m(\tau)$ for a two-sided LIM

From the analysis of Fig. 3 it is easy to see that in the case of a two-sided LIM, the energy efficiency of the separator increases with the decrease in the pole pitch of the inductor. At the same time, as follows from Fig. 4, the developed specific electromagnetic forces Fm with decreasing pole pitch τ decrease. With a small capacity of the separators (for example, at a material feed rate of less than 0,5 m/s), when the required separation force does not exceed 10 N/kg, extraction of metal particles with a particle size of 20 to 40 mm can be achieved at the pole pitch τ = 80-100 mm. This option will ensure the lowest power consumption of electrodynamic separators. As the productivity of the devises increases (for example, with an increase in the feed rate), inductor variants with large pole pitches (τ = 180-200 mm) are preferable. An additional advantage of such LIM variants used in separating metals from nonmetals is a smaller dependence of the force on the arrangement of the particles along the height of the gap. For example, in Fig. 4 on the left border of the graphs, the spread of forces in the center of the gap and on the surface of the conveyor belt reaches 30%, while at the right border of the graphs it does not exceed 5-7%.

When designing separators intended for solving problems of the second type (sorting of non-ferrous metals scrap), the evaluation criteria for options vary. When choosing the pole division of inductor of LIM the requirement of selectivity of separation comes to the fore. For qualitative sorting of alloys, it is necessary that in a given range of fineness the trajectories of particles with different physical properties do not intersect. The choice of the parameters of the traveling magnetic field and the corresponding linear inductor, taking into account the indices F_m, F_S and F_{mS}, is made only from variants that satisfy the selectivity conditions. In this case, it is necessary to take into account the influence of such perturbing factors as: changing the particle sizes within a specified range of particle size, changing their shape and orientation in a traveling magnetic field, and changing the electrical conductivity of particles belonging to the same group of alloys. Such changes can lead to a decrease in the difference between the specific electromagnetic forces acting on the particles of different alloys and the convergence of the trajectories of their motion. This increases the possibility of interbundling of the target fractions that are allocated during induction sorting. Therefore, when designing electrodynamic separators, it is necessary to minimize the effect of these perturbing factors.

In Fig. 5 shows the effect on the characteristics of the electrodynamic separator of the change in the thickness of particles of the separated aluminum alloys. Calculations are performed for plates with dimensions 40 × 40 mm. Four types of samples included in the groups of alloys with average conductivities γ = 35, 28, 20 and 15 MS/m (figures on the graphs) were used in the studies. The thickness of the plates varies from 2 mm (solid lines) to 12 mm (dashed lines). The working gap δ = 40 mm, the distance from inductor surface to the particle h = 5 mm.

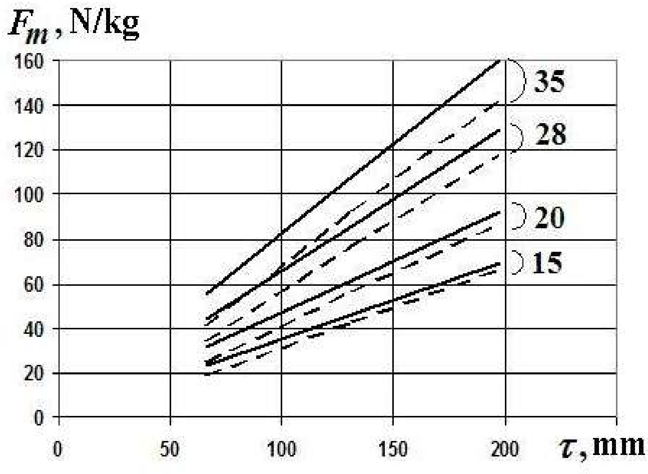

Fig. 5. To the choice of pole pitch of LIM separator for sorting aluminum alloys

As can be seen in Fig. 5, the regions (sectors) of the specific electromagnetic forces, corresponding to different groups of alloys, approach each other with smaller pole pitches. In the case of alloy groups with γ = 35 MS/m and γ = 28 MS/m, such regions intersect. Obviously, in order to increase the selectivity of separation of alloys, a large pole pitch (for example, in the range of τ = 150-200 mm there is a significant margin for the selectivity of the sorting) should be chosen.

In addition, we note that an increase in the pole division of inductors reduces the effect on the separation results of such factors as the shape of the metal particles and their orientation in a traveling magnetic field. In Fig. 6 shows the results of experiments obtained for an LIM with a two-sided inductor at pole pitches τ = 60 mm (solid lines) and τ = 180 mm (dashed line) in an electrodynamic separation installation schematically shown in Fig. 1,b. The experiments were performed on plates of aluminum alloy AMg3 (specific electric conductivity of about 20 MS/m), having the same surface area, but of different rectangular shape. For convenience of comparison, the final deflections of the particles (at the end of the inclined plane) from the feed line (B_*) are represented in relative units. For base values, the deflections reached for particles of square shape 40×40×3 mm are accepted.

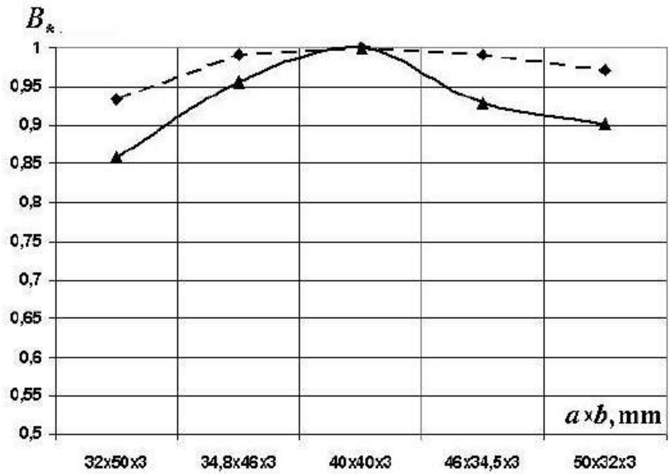

Fig. 6. Change in final deflections of particles from the supply line for different shapes and orientations of test plates in a traveling magnetic field

As can be seen in Fig. 6, at pole pitch τ = 60 mm, the change in shape and orientation of the plates in the field leads to a decrease in the deflections of the particles by 10-15% (at the edges of the range), which accordingly reduces the margin for the selectivity of separation of alloys. When switching to pole pitch τ = 180 mm, the deflections decrease is only 3-7%.

III. CONCLUSION

Thus, the performed studies show that the choice of pole pitch of linear inductors of electrodynamic separators is a multifactor task and depends on the purpose of electrodynamic separation units. In particular, the analysis shows that for the design of energy-efficient electrodynamic separators designed to solve problems of the first type (separation of non-ferrous metal particles from nonmetals), it is necessary to choose smaller values of the pole pitches of two-sided LIM from the variants corresponding to the condition of ensuring the operability of the installation. When solving problems of the second type (sorting of non-ferrous metal alloys), in order to increase the selectivity of sorting, large values of pole pitches are preferable.

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